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DISCUSSION OF DIVERSION TUNNEL AND POWER CONDUIT OF NANTAHALA HYDROELECTRIC DEVELOPMENT

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By Joseph R. Bowman and D. J. Bleifuss

POWER DIVISION

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DISCUSSION

JOSEPH R. BOWMAN,[6] ASSOC. M. ASCE.—The Nantahala development has become particularly noteworthy as the subject of several excellent papers describing in enlightening detail the solution of the many design, construction, and operational problems encountered. The project itself is outstanding in its utilization of many features which, at the time of their conception, were considered somewhat advanced over conventional practice.

Selection of Control Works.—The relative merits and economics of the control tower versus the control shaft are well presented. The writer has observed that in virtually every case in which the likelihood of earthquakes is anticipated the control shaft in rock has been found to be more economical than the free-standing control tower. Another type of control works occasionally investigated in conjunction with rock-fill dams or earth-fill dams is the inclined type, wherein the gate guide structure is constructed to conform to the natural slope of the mountainside. Under favorable circumstances this type possesses adequate stability against earthquakes at a worthwhile saving over the shaft in rock. If, however, the overburden is deep, the natural slope is too flat, or a heavy trash burden is anticipated, the inclined control works can prove to be rather expensive.

Outlet Tunnel Closure Bulkhead.—Although the "floating out" of the closure bulkhead is not a new idea, it has been somewhat less successful in a few cases in the past. The writer believes that the key to the successful use of this idea lies in selecting proper proportions of the buklhead. For a given head and closure area, a high and narrow bulkhead ordinarily weighs less than one having more nearly equal proportions, and, inasmuch as the seal friction and cubical content are very nearly the same in either case, the net result is that the high and narrow bulkhead is more buoyant. The writer should like to inquire as to whether the bulkhead was designed for use in future closures for inspection or for other purposes. He also ponders the fate of the intrepid soul who opened the by-pass valve and then dashed for the nearest exit 200 yd away.

Outlet Tunnel Energy Dissipator.—A rather well-defined trend toward the elimination of expensive stilling basins at tunnel outlets is seen in the location of more compact energy dissipators immediately downstream from tunnel control works. The writer recently attempted to adapt free discharge types of valves to subterranean control works for outlet tunnels, wherein the valves were arranged to discharge into a combination deflector and baffle-weir type of energy dissipator. It was found that conditions requiring the admission of large volumes of air through a conduit entirely separate from either the tunnel or the operating chamber frequently result in abandonment of the scheme.

NOTE—This paper by D. J. Bleifuss was published in December, 1949, *Proceedings*. The numbering of footnotes in this Separate is a continuation of the consecutive numbering used in the original paper.

[6] Civ. and Hydr. Engr., Harza Eng. Co., Chicago, Ill.

The writer suspects that the large round shaft immediatley downstream from the service gate slot in the Nantahala control shaft was not selected for reasons of access alone. A summary of the studies that guided the design of the Nantahala energy dissipator should be of considerable interest to engineers engaged in this branch of the profession.

Control Gates.—The choice of the type of gate used in both the outlet tunnel and the power conduit is of considerable interest to the writer. Preliminary considerations of the head and closure area alone could have resulted in the selection of a caterpillar-type gate, because the heads encountered at Nantahala are considerably higher than those heretofore imposed on fixed-wheel gates. Closer examination, however, again reveals the importance of proper gate proportions. The writer has made studies for the selection of gates in which hydraulic thrust on the gate is viewed in terms of a uniform load on the gate guides, with the result that the product of opening width (L) and the head on the center line of opening (h) forms a convenient parameter for the selection of vertical-lift gates. The application of this parameter ($L\,h$) to a large number of caterpillar and fixed-wheel gates installed over the past quarter century has led to the following generalizations as to submerged vertical-lift gates:

1. For gates operated in enclosed slots, such as the Nantahala gates—
   a. Fixed-wheel gates can be used economically for values of ($L\,h$) to 1,000; and
   b. Caterpillar-type gates should be used for values of ($L\,h$) exceeding 1,000.
2. For gates operated in exposed locations, such as on the face of a dam, fixed-wheel gates can be used for values of ($L\,h$) as high as 2,500.

In general, as the ($L\,h$)-value of a fixed-wheel gate is increased, the axle-mounted wheels gradually assume the proportions of rollers, and it becomes more economical to allow the gate leaf to bear directly on a larger number of smaller rollers.

Mr. Bleifuss undoubtedly is aware that the difficulties experienced with the top seals are not peculiar to the Nantahala gates alone. In spite of the objections to its use for this type of service, the J-seal is one of the most versatile types of seals yet devised. In some recent top seal applications the J-seals are so mounted that full water pressure is not applied until the gates are nearly seated, and the seals are guarded to prevent excessive deformation as the gates are opened.

The writer is interested to note the use of stainless steel for both the seal paths and wheel tracks. Corrosion resisting metals have been used as seal paths for many years, but only recently has it become practical to use such metals for wheel tracks. The vast improvements in the techniques of handling stainless steels have resulted in weldability and surface hardening without appreciable loss of corrosion resistant properties. A series of tests conducted by The Panama Canal[7] from 1941 to 1946 shows the corrosion resistance of the chrome-nickel steels to be far superior to those of other metals, whether exposed alternately or continuously to fresh, brackish, or salt water.

[7] "Long Term Metals Corrosion Investigation," prepared by The Panama Canal, *First Interim Report*, Balboa Heights, Canal Zone, January, 1947, Appendix I, Tables 3 to 7, inclusive.

Gate Guide Alinement.—In mentioning certain difficulties encountered in the alinement of guides for the power conduit control gates, the author has revived the writer's interest in a design problem that has been the object of widely divergent opinions, but which has been the subject of very little published discussion.

The failure of gate guides to assume true final alinement can be traced to one or more sources, the more fundamental of which include: (1) Insufficient rigidity of the guides; (2) inadequate provision for precise alinement prior to final embeddment; and (3) inadequate supervision or inspection of fabrication, handling, or field erection. Failure to comply with plans or specifications usually is caused by conditions beyond the control of the designer, but in most cases the provision of well designed guides and the choice of proper construction procedures are the responsibility of the design engineer.

Occasionally, however, the engineer is required to make the fabrication and erection costs of his designs conform to predetermined minimum costs. Recently, the writer was afforded the opportunigy of comparing the effects on alinement of the different types of gate guide construction used on two similar projects. In the first case, the guides themselves were of substantial construction, and provision was made for precise adjustment prior to final grouting. These practices resulted in nearly perfect guide alinement. In the second development, it was decided that both the construction of the guides and the provisions for alinement used on the first project were too expensive. Consequently, the guides were made considerably lighter than originally contemplated, and provisions for precise final adjustment were omitted so that the guides could be poured in place. These practices, together with an unsubstantial method of bracing the guides prior to concreting, resulted in a very unsatisfactory job of alinement. In addition to sags and humps, the final check revealed considerable warping of the wheel tracks. Fortunately, in anticipation of just such misalinement, the designers equipped the gate wheels with spherical roller bearings and other adjustments so that the inadequacies in guide design could be partly counteracted.

The theory (shared by many engineers) that structural steel erection tolerances are sufficiently accurate for gate guide erection should be reappraised. Thorough analyses made in connection with the Bonneville development[8] on the Columbia River show how guide deviations from "true," as small as a few thousandths of an inch, can result in seriously overloading the wheels of a gate. Furthermore, where seal clearances are very small, as in the case of the Nantahala gates, sagging or twisting of the guides can cause the gate seals to function improperly and may lead to the eventual destruction of the seals.

Gate-Opening Device.—The problem of reducing initial gate-opening forces has challenged the ingenuity of vertical-lift gate designers for several decades. By-pass valves and small filler gates have been used rather extensively to fill comparatively short conduits and thus obtain balanced head conditions prior to opening the intake gates. A valved by-pass would have been quite impractical at Nantahala, for it not only would have been well-nigh inaccessible,

[8] "Structural-Steel Tolerances at Bonneville," by T. M. Ober, *Transactions*, A.S.M.E., Vol. 64, 1942, pp. 721–729.

but also would have required a week to fill the 5½ miles of conduit. The lever-operated opening device installed on the power conduit control gates offers a most ingenious solution to this problem. Also, as the gate is lowered, this feature introduces the highly desirable characteristic of retarding the rate of gate movement shortly before the gate is seated. The writer would like to know whether this device has been patented.

Power Intake Gate Hoist.—Evidence of properly planning the gate and hoist as an intergral unit is seen in the simple and compact hoist arrangement. The writer will be interested to learn what arrangements were made for handling the emergency gate, as this point is not clearly shown in the paper. Also, the use of an automatic closure device is indicated in Fig. 12, but no description of the manner in which it functions is given.

The blower used to brake the descent of the gate during an emergency closure is one of the more reliable devices developed for this type of service, and many similar arrangements have been in successful operation for several years. The author states that in an emergency the gate is released simply by releasing the solenoid brake. Inasmuch as the principal recommendation for this type of brake is that it is applied when the power is cut off, it is questionable whether the brake could be released automatically in a "power-off" emergency. However, in view of the provision of interconnected sources of power for the gate hoists, it is highly improbable that an absolute power-off emergency would exist.

Pipe Line, Penstock, and Surge Tank.—It is encouraging to note the willingness on the part of a privately owned utility to accept the higher costs of field radiographing of pipe line welds in exchange for the benefits of an appreciable saving in materials, greater safety, and generally longer life of pipe line. Other recent improvements, notably the introduction of the ring-girder support and the development of more reliable field welding techniques, have led to the increased exploitation of the advantages of welded pipe lines.

In striking contrast with Pacific Coast practice is the omission of emergency works, such as a butterfly valve, at the head of the Nantahala penstock. The similarity in methods of penstock construction used recently in both sections of the United States seems to exclude the possibility of penstock rupture due to excessive pressure rise as the reason for this difference. Rather, it appears that greater susceptibility to earthquakes and exposure to falling boulders, in contrast to geological conditions at Nantahala, are responsible for the extensive use of emergency penstock closure works in the west.

The restricted orifice in the surge tank riser is to be admired for its simplicity. It is fairly well understood how the use of an orifice can effect marked economies in surge tank design, but the reasons for selecting a smaller discharge coefficient for the "load-on" condition could have been more clearly explained. It has been stated elsewhere[3] that design problems associated with the high head imposed on the Francis-type turbine do not permit the plant to be operated either as a peaking plant or a stand-by plant. Therefore, it was not necessary

[3] "Nantahala Turbine," by J. P. Growdon, R. V. Terry, and H. H. Gnuse, Jr., *Transactions*, A.S.M.E., Vol. 68, 1946, p. 687.

to design the surge tank for water supply demands caused by rapid increases in load.

Summary.—It is fitting and proper that a project embracing so many interesting features should be described in several papers, for in this manner many features otherwise overshadowed by the more spectacular can receive the individual treatment they so well deserve. The excellent form in which this paper is presented may well serve as a guide for many to follow.

D. J. BLEIFUSS,[9] ASSOC. M. ASCE.—

Outlet Tunnel Closure Bulkhead.—Mr. Bowman mentions that the successful use of the idea of floating out the bulkhead depends on its proportions. While holding back the water, the bulkhead is held in place by friction developed between it and the guides. When the water pressure is balanced this friction disappears, and if the bulkhead is buoyant it must rise to the water surface, provided it cannot "cock" in the guides and so become jammed in place. Bulkheads of varying proportions can be made buoyant, but a high and narrow bulkhead cannot "cock" and jam, where a low and wide bulkhead might. It is essential that the bulkhead and guides be so designed that no other force but friction caused by unbalanced water pressure can come into play to hold the bulkhead down.

The bulkhead was used only once, and after it floated up, it was scrapped. There was no practicable way to use the bulkhead for inspection or maintenance purposes.

There was no "intrepid soul" to open the by-pass valve. When the bulkhead was welded together, it proved to have a slight warp—that is, its downstream surface was not planar and consequently, when placed, it leaked. It was necessary only to close the gates downstream, and the leakage around the bulkhead filled the tunnel. The by-pass valve, provided for filling the tunnel, was never used.

Outlet Tunnel Energy Dissipator.—The correct design for the dissipator was determined by model tests. Mr. Bowman is correct in assuming that the round shaft was not intended for access alone; it was intended to supply air. Although the top of this shaft is in the gatehouse, air is not drawn from within the gatehouse. It was thought that there might be a diminution of pressure which might break windows or cause even greater damage, and provision was made for the entrance of air to the shaft directly from outdoors.

Gate Guide Alinement.—As a result of his experience at the Nantahala plant and elsewhere, the writer is most emphatically of the opinion that ordinary structural steel erection tolerances do not give sufficient accuracy for gate guide erection. Guides should be designed with screw supports permitting extremely accurate alinement before they are concreted in place. If the guides are not alined accurately, it becomes very difficult to build a gate that will not be overstressed somewhere at some point of its travel. It can be done, but too much machinery is required.

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[9] Chf. Engr., International Eng. Co., San Francisco, Calif.

Gate-Opening Device.—This type of device, which automatically provides for "cracking" a gate, has been used repeatedly by designers of the Aluminum Company of America. The writer does not know whether it ever was patented.

Power Intake Gate Hoist.—The two intake gates are in series, and are handled in identically the same fashion. As far as the writer knows, the automatic closure device was never installed.

In the writer's opinion, the blower is the most reliable braking device that could possibly be employed for this service. Probably the first gate hoists using blowers as brakes were the eight built for the Chute à Caron development on the Saguenay River in Quebec, Canada, about 1930. Ordinarily, the gates are lowered under power. When all power is off, the solenoid brakes at Nantahala must be released manually. At Chute à Caron, the solenoid brakes were operated by either alternating current or direct current and were so arranged that, when operated by direct current, they could be released by pushbuttons in the control room.

Pipe Line, Penstock, and Surge Tank.—The penstock was designed very carefully, and great care was taken in its construction. The possibility that the penstock would fail is extremely remote, and failure would be likely to occur only in the case of a natural disaster, such as a bad storm or an earthquake which might prevent the operation of a butterfly or other valve at the head of the penstock. Such a valve, therefore, appeared to represent a useless expenditure.

The writer felt that a complete discussion of the surge-tank design would have required too much space for inclusion in his paper and, as Mr. Bowman points out, some of the considerations involved have already been discussed elsewhere.

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